MASTER

COMPUTER ASSISTANCE FOR EXPERIMENTS ON THE ST-MACHINE*

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ABSTRACT

An IBM-1800 computer has been adapted by means of locally designed interfacing and control hardware (including a high-speed analog input mini-computer) and special software to perform for the ST-Machine real-time collection and processing of data and immediate display of results. Feedback thus provided assists in parameter adjustments and overall guidance in the experimental run.

Introduction

The data acquisition facilities for the large-scale experimental devices at PPPL were up-graded during 1970 by the inclusion of a programmable digital computer in order to provide:

- a) higher analog data taking rates,
- b) real-time verification of acquired data,
- c) means for driving alphanumeric and graphic display terminals, and
- d) some local computational ability.

In achieving these goals one might contemplate either a centralized computer system or a multiplicity of small computers -- a mini-computer for each plasma device or each experiment on the device. The latter is attractive in that conflicts for usage may be minimized and the inevitable problems that arise during the "debugging" of a new set-up would not affect other users. A sufficiently large central computer with input terminals having local buffering capacity can also take care of usage conflicts; a sophisticated monitor system can provide the integrity of operation of the computer as a whole, even while defects are being detected in some parts of the coding or interfacing. Such monitor systems usually require large amounts of main memory; however, this disadvantage is compensated by allowing the execution of so-called background programs concurrently with real-time data taking activities. In addition, a centralized computer facility will enjoy some economies of size and make possible the sharing of such peripherals as disk drives, tape units, program entry devices, digital-analog converters, etc.

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Also larger programs may be compiled on such computers in the higher level languages such as FORTRAN, so that the experimenters themselves can do most of the necessary coding. This capability, together with the larger amounts of general purpose software available with a larger computer, makes one of the biggest differences between using many mini-computers and one larger one: over-all much less systems programming manpower is necessary with a centralized computer facility.

DAS-1800, the data acquisition system of this paper, has as its central computer an IBM-1800, purchased in competitive bidding. As is seen in Fig. 1, the central processing unit has 32k 16-bit words, the usual peripherals for a disk-oriented computer, and built-in digital-analog conversion circuitry. In the case of most experiments, fairly extensive interfacing circuitry is necessary to connect external devices to the 1800. A small group of about five people at PPPL has been kept busy continuously designing and fabricating such equipment. Thus it has been feasible to interconnect the IBM-1800 with PDP-8 mini-computers for use as high-speed analog front-end terminals. Other non-IBM equipment in DAS-1800 include Tektronix storage oscilloscopes ("memoscopes") and associated hard-copy unit, as well as, of course, the apparatus of the different experiments.

Data Requirements for the ST-Machine

The ST-Machine is both typical of the plasma devices DAS-1800 was envisioned to serve and, in fact, the machine that is making the most extensive use of the facility at the present. The rest of this paper will be devoted to an exposition of the methods used to meet the requirements of the ST-Machine in general and a little about the specific experiments.

Data Input

Since the ST-Machine is a pulsed device, having a typical period of 20 to 30 seconds, data taking is naturally related in timing to these pulses or "shots." Data about the current operating parameters of the machine are available in digital form from an independent logging

system (DATA) and are read automatically by the computer between pulses. Parameters and instructions may also be manually entered by the experimenters between pulses. The actual data from the different experiments, on the other hand, may be acquired by the computer:

- a) in analog form during the typically 50ms pulse (real time),
- b) also in analog form, but after the pulse from sample-and-hold circuits, or
- c) in already digitized form after the shot from the stored memory of a mini-computer terminal.

Thus large amounts of experimental data may be acquired during the rather short machine pulse and transferred to the central computer without serious timing problems. In addition to these types of data that are sent to the computer each shot, there are data from scalars that may sum counts over many pulses for transfer to the computer every half-hour or so.

Data Verification

The physicists who are operating the computer from their machine control room (remote from the computer room) require verification of correct procedures and validation of the data being acquired. Such manual entry facilities as thumbwheel switches are self-verifying in that they retain the settings and are provided with a light to indicate that they have indeed been read. Other lights at the experimenters' locations depict the status of the computer, the state of enabling gates, etc. Machine parameters and other such small amounts of digital data along with textual comments may be written on the different memoscopes or on the log printer in the ST-Machine control room. The raw data usually are voluminous enough that the most convenient method of verification is plotting in graphical form on a memoscope. Finally, of course, there is negative verification provided by error lights from either the computer or an interface in the control room or by error messages on the memoscopes or on the serial printer.

Calculations and Output

Once the data are in the computer, there are many levels of processing or calculations possible. Most often the data have to be converted from the natural binary representation used internally by the computer to "engineering" units such as volts, joules, gauss, etc. In many cases corrections have to be made for transducer sensitivity, base line, or geometry. Sometimes standard methods of curve smoothing or fitting can be applied and results implied directly. For some

experiments formulas, ranging from rather simple to somewhat complex, are applied to the data on a shot-to-shot basis to obtain the required results. In other cases the data from several shots are required to correct for different effects or to provide signal averaging. Then one of the things that the computer can do in a rather trivial manner to save the experimenter from long periods of tedious work is to transpose a matrix of data representing a signal vs time, with a parameter such as probe position changed from pulse to pulse. The transposition gives the signal as a function of this parameter for different times in the pulse.

Since data acquisition is performed at a higher priority level, all this data manipulation has to be done during the 20 or 30 seconds between pulses; to be useful in real-time guidance of the physicist in conducting his experiment, it must be completed well before the next pulse. In principle, extensive calculations could be done on the data by transferring them via magnetic tape to the University's IBM-360/91 computer; in practice this has yet to be necessary. Often, however, data saved on disk or magnetic tape during a run are subjected at some later time to further processing in order to obtain more information or to try different parameters, constants, or formulas.

Just as in the case of raw data, the final results may be plotted as curves on a memoscope or as numbers and text on a memoscope or on the serial typer. This "log" printer, as the name implies, is used to record significant operating parameters and perhaps bellwether results during the run, and at the end of a run to list summaries of all results by means of programs that scan the data files just created.

Software

The total software to do the things just outlined falls naturally into three categories: that provided by IBM, by members of the Instrumentation Section, and by the user-experimenters. IBM furnishes the monitor system, the Multiprogramming Executive Operating System (MPE), the standard compilers, assemblers, arithmetic, timing, and control functions, and routines callable directly from FORTRAN programs for performing the special input/output functions concerned with the "process" connections to the experimental apparatus. Also, IBM distributes other programs and routines written for the 1800 computer by users. An example of this latter type is the extensive set of

routines for alphanumeric and graphic output to the memoscope. These efficient routines, which are callable directly from FORTRAN programs, would require many man-months of programming effort to duplicate. The systems routines written by members of the Instrumentation Section consist of those which direct the over-all operation of the computer (assign priorities and the like), those which could affect the integrity of the system as a whole, and those which are too involved to be written by the users (such as data acquiring routines). Finally, there is the large body of programming done by the experimenters with perhaps the help and guidance of regular programmers. These are the routines that identify and sort the data obtained by the systems programs, do the required manipulations and calculations, and then display and/or store the data and results.

Extra Hardware

Much more hardware than that provided by IBM is necessary for a data acquisition system for the ST-Machine. Since the logic levels for digital input do not match those for digital output and neither matches those of current TTL design, it is necessary to build interfacing for data lines and in addition for synchronizing the transfer of the data. By means of a circuit for shifting and inverting the digital output signals from the 1800 it is possible under program control to "strobe" data entry and control switches through diodes onto a single 16-bit input data bus, which is run throughout all control rooms. This arrangement for all low-speed digital data not only saves installation and cable costs, but also conserves the digital input facilities of the computer. The 4-bit output of 15-button numeric keyboards and the 8-bit output of full-typewriter keyboards may be combined in any manner that produces 16 parallel bits of encoded information (with one code, all ones, indicating that a specific keyboard is not entering data when another with which it is paralleled is). Similarly, groups of four hexidecimally encoded thumbwheel switches produce a 16-bit input word. Some of the devices which are read onto the data bus, however, are part of a pre-existing tab card data logging system, DITEI. For these switches, thumbwheels, and DVH's the data come in one digit at a time in the standard Hollerith code, which is decoded by software in the 1800.

Another type of locally produced interfacing equipment is seen in the left-hand cabinet in Fig. 2; this integrates the functions of both computer and experimental apparatus, providing

partial sequencing of operations, etc., so that the physicist is relieved of some of the work of running his experiment and some possible human errors may be avoided. Although sometimes extensive local hardware logic is provided by these circuits, the experimenter is still part of the feed-back loop -- full automation has not yet been attempted.

The right-hand cabinet in Fig. 2 contains the PDP-8/I mini-computer and the multiplexer and analog-to-digital converter chassis which constitute the high-speed analog data terminal.[1] This facility permits one to six channels of analog data to be acquired and digitized either sequentially or simultaneously at rates up to once every 1.5 microseconds (cf. 50 usec/point for the 1800), stored in local core memory, and subsequently transferred to the 1800 at about a 50kHz rate. At present, design consideration is being given to facilities for sending messages back to the terminal or for loading its memory with programs from the 1800, as well as to other terminals having more channels. The interfacing for a so-called Graf pen is now under construction. This system will be used for digitizing curves or in conjunction with a large-screen memoscope for a myriad of interactive data-entry activities such as free-hand curve fitting, removal of erroneous data points, etc. Two other hardware projects now being considered, which would improve the 1800 computer and make it more useful to the ST-Machine and others, are an interface to an inexpensive non-IBM high-speed line printer and the addition of floating-point hardware (not available from IBM).

ST-Machine Experiments

The specific experiments now using the DAS-1800 facilities range from those which simply feed normal oscilloscope signals to the computer in order to obtain more convenient display of shot-to-shot results to those requiring extensive special interfacing and control hardware and those which without the computer would be infeasible because such large amounts of data are involved.

Pick-up Loops

One of the convenient diagnostics used with the high-current, Tokamak-type plasma discharge in the ST-Machine is the pick-up loop. In one case a loop enclosing the plasma column is compared to another similar loop not enclosing the column and the resulting signal is sent through an integrator to DAS-1800 along with a signal that is proportional to

current in the ohmic-heating pulse, which drives the current through the plasma. By applying these to a formula containing the value of the confining magnetic field as a scaling factor, one component of the plasma pressure is obtained directly as a function of time and plotted on a memoscope. Another pair of small pick-up loops is located along a major radius of the machine, oriented normal to the field produced by the current flowing through the plasma column, one on either side. Signals from these loops, also sent through integrators, along with the time-varying current signal from the ohmic-heating pulse, the value of the confining field, and the setting of the limiter (which determines the diameter of the plasma column), are used by the computer for data in an integration which yields the sum of plasma pressure components and inductance per unit length and the horizontal shift of the plasma column, both as functions of time. These are plotted on a memoscope as in Fig. 3. Another experiment using pick-up loop signals now in the planning stage promises to display the changes in effective plasma inductance as a function of time.

Heavy Ion Beam

A diagnostic tool recently added to the ST-Machine is apparatus for producing and focusing a beam of singly ionized thallium ions, sweeping this beam across the plasma column, wherein it can be further ionized by the energetic electrons of the plasma, then performing energy and momentum analyzing of the doubly ionized beam produced along a line through the column. As indicated in the schematic diagram of Fig. 4, analog computer components control the analyzers from error signals at the beam detector. The control signals are proportional to the space potential and the axial component of the vector potential, respectively, for the point in the plasma at which the second ionization took place. These control signals, difference signals (which indicate improper operation), the total beam current detected, and the sweep signal are fed to the PDP-8/I analog data terminal, which samples them at about a 100kHz rate, storing some 500 sets of data for transmission to the 1800 after real-time data collection for the pulse is completed. The digitized form of whichever of these data are desired is displayed on a memoscope (Fig. 5) and all the data are stored on magnetic tape for post-run processing.

Many things can be deduced by the data obtained from this multi-purpose experiment: the local electron density (assuming a knowledge of electron

temperature from other experiments), the current density, electric and magnetic fields, and angular velocity of the electrons along the "detector line" (and therefore throughout the plasma column, if it has rotational symmetry)).

Spectroscopy

Computer connected monochromators on the ST-Machine are used to make both radial intensity scans and Doppler broadening determinations. The radial scans are performed by a monochromator mounted on the same carriage mechanism used by the Thomson scattering apparatus (to be discussed later). The photomultiplier signal is recorded as a function of time by the 1800 A/D converter at about a 20kHz rate for each shot. The digitized signal is displayed on a memoscope soon after the shot. Between shots the carriage is stepped along a major radius of the machine, so that the light intensity for the selected wave length is determined for different radial positions in the plasma column. After a scan is completed, the data in the matrix stored on disk are transposed so as to obtain intensity vs radius for selected time slices. Various of these time slices are usually displayed on a memoscope, and hard copies made. In the case of the Doppler broadening scan the technique is much the same, except that here the position of the monochromator is fixed and the wave length is varied from shot to shot over a small range. At the end of the scan the matrix is transposed as above and then a curve-fitting program determines for each time slice the center of the broadened spectral line, the width at half-maximum (which defines the temperature), and the total line intensity. These results are then listed on the printer.

Thomson Scattering

The Thomson scattering experiment described previously,[2] started using DAS-1800 within three weeks after IBH installed the 1800 computer. Although both the hardware and the software have been greatly improved over the intervening period, the experiment itself remains the same: The beam from a 4-joule ruby laser is directed from the scanning mirror up to the plasma, where it is Thomson scattered by energetic electrons. The spectral line broadening of the light scattered back at 90 degrees is recorded at the desired time during the pulse by a seven-slit polychromator, the photomultiplier currents from which are stored on integrating capacitors for post-shot readout to the computer. From a series of readings taken under different conditions

(with and without plasma, with and without laser beam, etc.) the necessary corrections to the data are made and the seven points are least-squares fitted to a Gaussian distribution, the width at half maximum indicating electron temperature and the total intensity giving density. Figure 6 shows the memoscope display of such data and Fig. 7 is a scan summary of temperatures as a function of radial position of the laser beam with respect to the plasma column.

X-Ray Spectra

Recently an interface for a Northern Scientific 710 pulse-height analyzer has been completed. This makes possible the transfer of the 1024 channels of counts to the 1800 at a 50kHz rate. The analyzer is used with various X-ray detectors to determine electron bremsstrahlung spectra, from which it is possible to deduce electron velocity distributions. The counting rate is so small that some 50 shots are necessary with each of three different foils; thus the counting period for each spectrum is over an hour. A modification is currently being made on the analyzer to allow four different spectra (for different times during the machine pulse) to be recorded in different blocks of channels.

The extensive software that will be necessary for the ultimate direct calculation of the electron velocity distribution has just begun. At present it is only possible to transfer the data from the pulse-height analyzer every 50 shots and display the uncorrected spectra on a memoscope. Even the first programs that will make the necessary corrections for sensitivity curves, etc., will probably require five to ten minutes of computer time; however, since this will occur only every hour or so, it will be tolerable.

Future Experiments

One experiment that is currently being run on the ST-Machine which will undoubtedly need the help of DAS-1800 is the scattering of 2mm microwaves by the electrons in the plasma. The signal-to-noise ratio is so small that the only apparent hope is to do signal correlation over perhaps 100 shots. Another experiment involving large amounts of data is the electronic streak camera. An interface is being designed to read 13 channels into the PDP-8/I terminal at rates up to one channel every 3 usec for post-shot transmission via the 1800 to magnetic tape.

Summary and Conclusions

DAS-1800 has for over a year now been serving the ST-Machine by doing real-time data collection, processing, and display, thus giving information to the experimenters on a shot-to-shot basis, by providing extended calculations to relieve the experiments of tedious post-run data reduction, and by recording and immediately verifying voluminous raw data for subsequent manipulation and correlation with other data.

Previously, when the LSP-1 machine was running, DAS-1800 could serve either ST or LSP, but not both at the same time. Changes have been made in the DAS-1800 operating system so that both the ST-Machine and the new PH-1 (which has replaced LSP-1), are able to operate concurrently, with a minimum of interference.

The experience that has been gained in providing data acquisition service for LSP-1, ST-Machine, and now PH-1 is aiding in the design of the facilities for use with ATC, now under construction. In order for DAS-1800 to keep pace with the development of new fusion research devices, however, it will be necessary in the near future to add more core memory and another disk storage unit to the 1800 computer, to provide more data buffering capability at the machine control rooms by means of mini-computer terminals, and perhaps even to employ special purpose mini-computers to help the 1800 with specific tasks.

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REFERENCES

[1] F. K. Bennett, S. Schweitzer, J. J. Mayercak, *IEEE Transactions on Nuclear Science*, **NS-18**, 113 (1971).

[2] P. A. Thompson and D. E. Huttar, *IEEE Transactions on Nuclear Science*, **NS-18**, 106 (1971).

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Fig. 1. Schematic diagram of present DAS-1800 system.

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Fig. 2. The section of the ST-Machine control room devoted to computer-related experiments, showing a rack containing laser and spectrometer controls (some of which are integrated with computer control circuitry), another rack containing analog data line-driver amplifiers and associated patching facilities, a mobile rack containing the high-speed analog data terminal for DAS-1800 (with attached display scope), and a table containing two memoscopes, an intercom to the computer, a keyboard input device, and a 1053 serial printer.

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Fig. 3. Memoscope output from loops experiment, showing shot number and ST-Machine parameters with curves of both raw data and results plotted from integration calculation.

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Fig. 4. Schematic of the Heavy Ion Beam experiment, showing analog computer components and connection to DAS-1800.

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Fig. 5. Memoscope output from Heavy Ion Beam experiment, showing PDP-8/I terminal settings and vector potential, space potential, and density signals displayed with the beam sweep trace.

838 1.09 JOULES
POS = 250MM DELAY = 20.0MSEC
TEMP = 1127.83+/- 112.5 EV
DENS = 31.36+/- 1.15 E12 CM-3

714091

Fig. 6. The fit of corrected Thomson scattering data to a Gaussian, with inferred electron temperature and density and input parameters.

714097

Fig. 7. Summary plot for a complete scan of Thomson scattering temperature in eV as a function of radial position on 300 mm scale (dashes indicating different temperature determinations at a position and dots the calculated probable errors).